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User's Guide to Version 2 of the Regeneration Establishment Model: Part of the Prognosis Model

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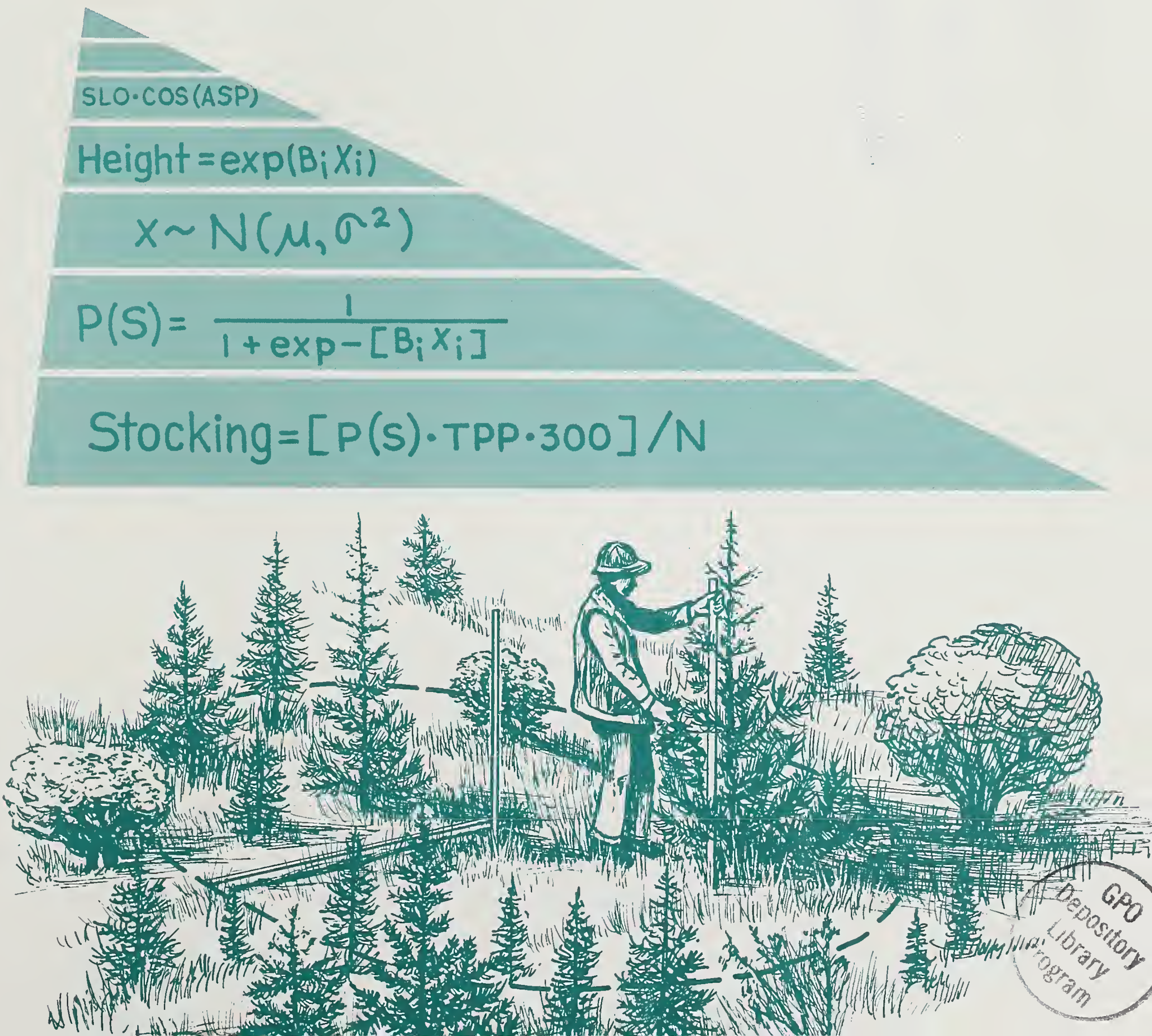

THE AUTHORS

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RESEARCH SUMMARY

Version 2 of the Regeneration Establishment Model is part of version 6 of the Prognosis Model for Stand Development. The regeneration model predicts results of regeneration harvests for most site and stand conditions found in the Northern Rocky Mountains. The model is based on analysis of 12,128 1/300-acre plots sampled in forests of western Montana, and central and northern Idaho, and includes the influence of western spruce budworm (*Choristoneura occidentalis* Freeman) defoliation on regeneration success. Direct linkage to the Prognosis Model allows projections from one rotation to the next. Both even-age and uneven-age management can be simulated. Model characteristics, prescription options, program control, and regeneration summaries are discussed.

ACKNOWLEDGMENTS

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CONTENTS

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INTRODUCTION

Forest stand characteristics change rapidly following a regeneration harvest. The new stand density, species composition, and vigor are determined during the regeneration period. No other silvicultural treatment creates such pronounced changes in the stand for long periods of time. Delays in obtaining stocking, poor stocking, or poor vigor reduce future yields.

The chances of achieving a regeneration goal depend on many factors that interact during the regeneration period. Land managers need a tool to predict the results of regeneration harvests, both as a guide for forest regeneration and as input to growth and yield planning. This tool must quantify results of the regeneration process in a statistically and biologically sound manner.

Stage (1973) recognized the need for a regeneration model that was linked to predictions of long-term growth and yield. He envisioned the regeneration model as one of three submodels in the Prognosis Model for Stand Development:

1. Establishment of regeneration stands, including ingrowth into existing stands.
2. Transition from regeneration phase to individual tree phase.
3. Development of individual trees.

The three submodels were first made available with version 5 of the Prognosis Model (Wykoff 1986) that included version 1 of the Regeneration Establishment Model (Ferguson and Crookston 1984). Further development has led to version 2 of the Regeneration Establishment Model. The purpose of this paper is to explain the use of version 2 of the Regeneration Establishment Model. Uses of the regeneration model include the following:

- Deciding upon a regeneration prescription that best meets management objectives.
- Linking regeneration to long-term growth and yield.
- Predicting regeneration in long-term projections of succession or uneven-age management.
- Developing harvesting schedules.
- Helping in other areas of forest planning where regeneration is important for watershed, wildlife, esthetics, and so on.

Version 2 of the Regeneration Establishment Model is calibrated for western Montana and central and northern Idaho (fig. 1). It includes the

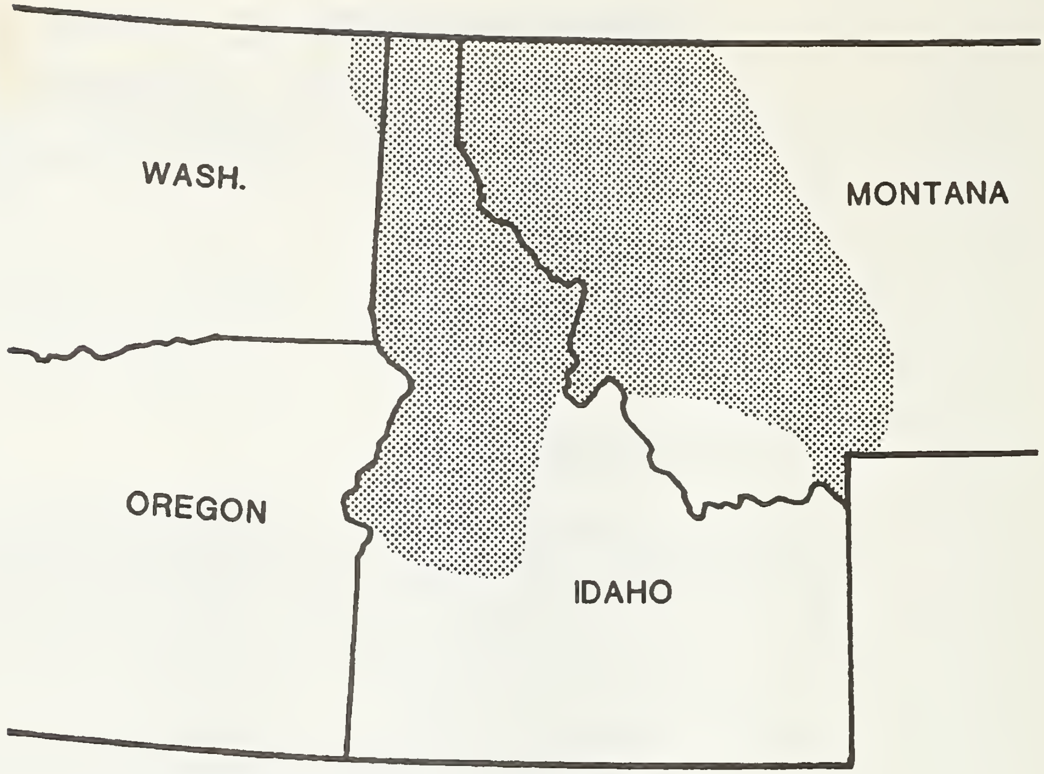

Figure 1—Study area (shaded) for version 2 of the Regeneration Establishment Model.

11 commercial species listed in table 1. Most common habitat types are represented in the model—the Douglas-fir climax series, the grand fir series, the western redcedar series, the western hemlock series, the subalpine fir series, and some of the mountain hemlock series. In addition, the model represents the effects of western spruce budworm (*Choristoneura occidentalis* Freeman) defoliation on the process of regeneration establishment. When the regeneration model is used as part of the western spruce budworm modeling system (Crookston and others 1990), budworm effects are automatically represented.

BACKGROUND INFORMATION

The Prognosis Model

The Prognosis Model is a forest growth and yield model that has been calibrated for various forest regions. Regional versions are called *variants*. For example, the Inland Empire variant of the Prognosis Model represents 11 species in forests of northern Idaho and adjacent forests in Montana and Washington (Stage 1973; Wykoff and others 1982).

The Prognosis Model projects the increment of individual trees over time. An inventory of trees is maintained in a *tree list* that represents a stand of trees. Time steps in the model are called *cycles*. Cycles can vary in length—the default cycle length is 10 years. In each cycle, the model accounts for growth and mortality as well as implementation of silvicultural prescriptions (fig. 2).

Prognosis Model removals (harvests and thinnings) are simulated at the beginning of the cycle. Regeneration is predicted at the end of the cycle after removals, growth, and mortality have been simulated.

Table 1—Scientific name, common name, species codes, and minimum establishment height for regeneration

Scientific name	Common name	Numeric code	Abbreviation	Minimum height
				Feet
Pinus monticola Dougl.	western white pine	1	WP	1.0
Larix occidentalis Nutt.	western larch	2	L	1.0
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	Douglas-fir	3	DF	1.0
Abies grandis (Dougl. ex D. Don) Lindl.	grand fir	4	GF	.5
Tsuga heterophylla (Raf.) Sarg.	western hemlock	5	WH	.5
Thuja plicata Donn ex D. Don	western redcedar	6	C	.5
Pinus contorta Dougl. ex Loud.	lodgepole pine	7	LP	1.0
Picea engelmannii Parry ex Engelm.	Engelmann spruce	8	S	.5
Abies lasiocarpa (Hook.) Nutt.	subalpine fir	9	AF	.5
Pinus ponderosa Dougl. ex Laws. var. *ponderosa*	ponderosa pine	10	PP	1.0
Tsuga mertensiana (Bong.) Carr.	mountain hemlock	11	MH	.5

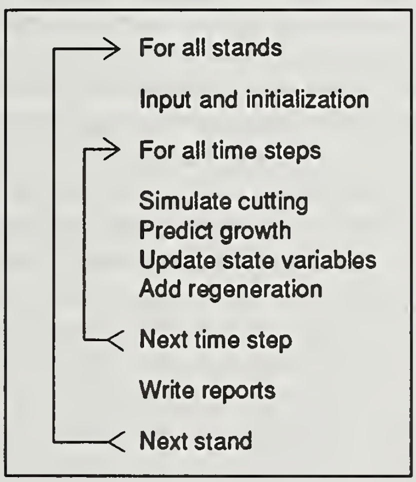

Figure 2—Time sequence for steps in the Prognosis Model.

An inventory of trees on one or more plots represents a stand in the Prognosis Model. The trees per acre represented by each inventory tree is a function of the inventory plot size and the number of plots sampled in the stand. For example, each tree sampled on one 1-acre plot represents 1.0 tree per acre, each tree sampled on two 1-acre plots represents 0.5 trees per acre, each tree sampled on ten 1/300-acre plots represents 30 trees per acre, and so on. Plot attributes that change are updated each cycle for use by other submodels. The regeneration model makes extensive use of plot information.

Regeneration Model Concepts

A call to the regeneration model can be scheduled at the end of any Prognosis Model cycle. ("Call" is computer jargon indicating that a certain computer program is to be used—in this case it is the regeneration model.) When called, the regeneration model uses the updated inventory to predict new regeneration. New trees are added to plots that correspond to the inventory plots in the Prognosis Model. Each plot can have unique attributes such as slope, aspect, habitat type, site preparation, overstory density, and overstory species composition. Use of this plot information provides some spatial resolution to the regeneration model. Predictions are made for each plot, then averaged to produce stand statistics.

Regeneration is added to the Prognosis Model tree list at the end of the cycle in a regeneration *tally*. A tally is similar to results of a regeneration survey for a stand—the regeneration process continues for a variable number of years before it is quantified by a regeneration survey.

The *regeneration period* is the number of years during which regeneration becomes established as a result of a disturbance. The length of the regeneration period varies depending on site, but for modeling purposes, it is set at 20 years. Regeneration that occurs after the regeneration period is called *ingrowth*. Ingrowth is both the result of succession by shade tolerant species and the continued regeneration of trees into gaps in the tree canopy.

Regeneration Model Study Design

This section provides a brief description of the study design used to obtain data for the Regeneration Establishment Model. Full details are found in Ferguson and Carlson (in preparation) and Ferguson and others (1986).

Stratified random sampling was used to select stands that were operationally harvested 2 to 20 years prior to sampling. Stands from USDA Forest Service, State, and private timber ownerships were classified by habitat type, site preparation, regeneration method, geographic location, and history of budworm defoliation. Four to five stands within each combination were randomly chosen for sampling.

Stand histories and aerial photographs were obtained for each selected stand. Either transect segments or a sampling grid was used to systematically locate about 25 sampling points per stand. Each sample point was the center of a 1/300-acre circular fixed area plot and a variable radius plot for sampling the overstory with a 10-factor prism.

Habitat type, slope, aspect, type of site disturbance, topographic position, and overstory density by species were recorded for each 1/300-acre plot. Year of cutting, geographic location, and elevation were the same for all plots within a stand. All conifer regeneration on each plot was counted by species. Height and age were recorded on a subsample of *best trees*.

Best trees play a key role in the linkage to the Prognosis Model. The idea of best trees follows from the fact that many more trees reproduce than will exist in the mature forest (Wellner 1940). By selecting a few trees on each stocked plot, attention is focused on the growing stock that will contribute to yield. Best trees are chosen by the following rules:

- Select the two tallest trees on each 1/300-acre plot regardless of species.
- Select the one tallest tree of each additional species represented on the plot.
- If the first two rules do not total four trees, select in order of descending height from any remaining trees, if present, until four are chosen.

Conifers included in the regeneration model are shown in table 1. This table also shows the minimum establishment height by species—these heights are 0.5 feet for shade tolerant species and 1.0 foot for shade intolerant species. Maximum size of regeneration is 2.95 inches diameter at breast height (d.b.h.).

The experimental unit was the 1/300-acre plot. Plots were either stocked by at least one seedling or they were non-stocked. All plots were used to develop equations predicting the probability of a 1/300-acre plot being stocked. The probability of stocking is continuous in the interval [0,1], indicating the proportion of plots with one or more established seedlings. Then, only stocked plots were used to develop equations predicting the number of trees per plot, species composition, and seedling heights.

Table 2 shows which independent variables recorded during sampling are used to predict dependent variables in the regeneration model. Regression equations can be found in Ferguson and Carlson (in preparation).

Table 3 shows the habitat types, number of plots, and habitat type groups for data used to develop version 2 of the Regeneration Establishment Model. Groupings were made by statistical analyses of the data that compared the percentage of stocked plots, trees per stocked plot, and species per stocked plot (Ferguson and Carlson in preparation). Some habitat types were poorly represented in the data (too few plots) and they were subjectively placed with a group thought to be similar. Groupings were reviewed by forest ecologists—their suggestions were used to develop the final groupings.

Table 2—Summary of dependent and independent variables used in the Regeneration Establishment Model. A plus sign (+) indicates that the independent variable is used to predict the dependent variable. Model coefficients and formulations can be found in Ferguson and Carlson (in preparation) and Ferguson and others (1986)

Independent variable	Dependent variable: Probability of stocking	Number of trees/plot	Species composition	Seedling heights
Stand variables:				
Elevation	+		+	+
Geographic location	+		+	
Budworm defoliation	+	+	+	+
Plot variables:				
Habitat type	+	+	+	+
Slope	+	+	+	+
Aspect	+	+	+	+
Topographic position			+	+
Residual overstory basal area	+	+	+	+
Residual overstory species composition			+	
Time since disturbance	+	+	+	
Site preparation	+		+	+
Seedling density				+
Other:				
Seedling age				+

Table 3—Number of plots by habitat type and habitat type group

Group	Habitat types[1] (number of 1/300-acre plots)	Total number of plots
1	PSME/VAGL, LIBO, VACA (178) (92) (26)	296
2	PSME/CARU, CAGE, AGSP, FEID (264) (122) (26) (5)	417
3	PSME/PHMA, ACGL (815) (17)	832
4	PSME/SYAL, SPBE, SYOR, ARUV, Misc (568) (223) (75) (18) (3)	887
5	ABGR/LIBO, CLUN-XETE (199) (74)	273
6	ABGR/XETE, VAGL, COOC, VACA (248) (177) (13) (13)	451
7	ABGR/CLUN (except CLUN-XETE)	1,865
8	ABGR/SPBE, ACGL, PHMA, ASCA, SETR (447) (251) (151) (138) (2)	989
9	THPL/All	2,180
10	TSHE/All	1,387
11	ABLA/VAGL, VASC, VACA (176) (110) (56)	342
12	ABLA/XETE, LIBO (533) (142)	675
13	ABLA/CLUN, GATR (673) (7)	680
14	ABLA/CAGE, CARU, ACGL, SPBE (105) (73) (36) (14)	228
15	ABLA/MEFE, ALSI (353) (31) TSME/CLUN, XETE, MEFE, STAM (31) (31) (9) (5)	460
16	ABLA/CACA, STAM, LUHI (107) (55) (4)	166
Total		12,128

[1]Species codes for habitat type abbreviations:

ABGR	*Abies grandis*	ABLA	*Abies lasiocarpa*
ACGL	*Acer glabrum*	AGSP	*Agropyron spicatum*
ALSI	*Alnus sinuata*	ARUV	*Arctostaphylos uva-ursi*
ASCA	*Asarum caudatum*	CACA	*Calamagrostis canadensis*
CAGE	*Carex geyeri*	CARU	*Calamagrostis rubescens*
CLUN	*Clintonia uniflora*	COOC	*Coptis occidentalis*
FEID	*Festuca idahoensis*	GATR	*Galium triflorum*
LIBO	*Linnaea borealis*	LUHI	*Luzula hitchcockii*
MEFE	*Menziesia ferruginea*	PHMA	*Physocarpus malvaceus*
PSME	*Pseudotsuga menziesii*	SPBE	*Spiraea betulifolia*
STAM	*Streptopus amplexifolius*	SYAL	*Symphoricarpos albus*
SYOR	*Symphoricarpos oreophilus*	THPL	*Thuja plicata*
TSHE	*Tsuga heterophylla*	TSME	*Tsuga mertensiana*
VACA	*Vaccinium caespitosum*	VAGL	*Vaccinium globulare*
VASC	*Vaccinium scoparium*	XETE	*Xerophyllum tenax*
SETR	*Senecio triangularis*		

Data used to develop the regeneration model came from 12,128 1/300-acre plots sampled in 537 stands. Stands were chosen in an unbiased manner. Most stand and treatment conditions commonly found in the Northern Rocky Mountains

are included in the data. The data represent all aspects, 0 to 110 percent slopes, 0 to 390 square feet per acre of residual overstory basal area, 2,400 to 7,400 feet elevation, and 0 to 16 years of budworm defoliation. Model results should predict what can be expected under actual implementation of regeneration prescriptions because the data were collected from stands harvested by conventional means.

USING THE REGENERATION MODEL

Predicting New Trees

The Regeneration Establishment Model simulates the regeneration process by creating a list of tree records describing new trees on ⅓₀₀-acre plots. Regeneration is summarized in a table reporting the average probability of stocking for ⅓₀₀-acre plots, total trees per acre by species, identification of best trees from the list of total trees, and average estimated heights of best trees. New tree records are added to the Prognosis Model tree list, then growth and development of the stand continues.

To predict regeneration, the inventory at the end of the current Prognosis Model cycle is used along with a silvicultural prescription that you supply. A call to the regeneration model is scheduled through the use of keywords and by automatic calls. In a typical situation, you schedule a call to the regeneration model following a simulated harvest. In other situations, the regeneration model is automatically called when trees have been removed or when ingrowth is to be added to the stand.

Regeneration is reported in a summary called a tally. At each tally, new regeneration is added to the Prognosis Model tree list and a regeneration summary output table is printed. Tally dates are a function of the cycle length and the year of disturbance. Whenever there is a cycle boundary within the 20-year regeneration period, a tally of regeneration will be predicted and the new trees added to the tree list. Thus, 5-year cycle lengths would result in four tallies of regeneration. A series of tallies that occurs during a regeneration period is called a *tally sequence*.

A regeneration tally sequence is scheduled when a date of disturbance is specified—tallies are scheduled at cycle boundaries for the next 20 years. If tallies are desired only at certain cycle boundaries, you can specify up to two times when the regeneration will be summarized and added to the inventory.

Because regeneration is added at the end of the cycle, the number of years of regeneration appears to be 1 year less than the cycle length. For example, if the Prognosis Model is using 10-year cycles beginning in the year 2000, regeneration would be added in the "fall" of 2009. A total of 10 growing seasons has elapsed from 2000 to the fall of 2009. The new trees would appear in Prognosis Model summary tables beginning in 2010.

Planting can be accomplished any time during the 20-year regeneration period. Multiple plantings are allowed; for example, the same species could be planted more than once during the regeneration period. You specify the year of planting, species, trees per acre, expected survival, seedling age (optional), average height (optional), and shade preference (optional). In partial cuttings, shade preference allows seedlings to be planted at higher densities under the shade or at higher densities in the sun.

The regeneration model can simulate the effects of site preparation. Individual plots may be mechanically scarified, burned, or left untreated. Site preparation can occur at years other than the year of disturbance, but they should be scheduled sometime during the first tally. Site preparations

scheduled after the first tally in a tally sequence are cancelled because some trees from the first tally would be killed, and we have no way to predict this mortality at the present time.

When an actual inventory is used to initiate the Prognosis Model, the regeneration model calibrates the probability of stocking to adjust for differences between the actual inventory and the predicted stocking. This feature adjusts the stocking curve (predicted) to coincide with a known reference point (inventory). A stand already stocked with many trees per acre has little room for increases in stocking whereas each additional seedling in a sparsely stocked stand has a greater probability of stocking another plot.

All best trees are passed to the Prognosis Model for simulation of future stand development and are coded as being "desirable" trees (see tree value codes, p. 99, in Wykoff and others 1982). Up to five trees of each species not chosen as best trees are passed to the Prognosis Model but are coded as being "acceptable" trees. In subsequent thinnings simulated by the Prognosis Model, a higher priority is given to the removal of acceptable trees than is given to desirable trees, all other things being equal.

Automatic Tallies

Sometimes, thinnings remove enough trees to allow regeneration to become established. These situations are detected by the Prognosis Model, and regeneration activities are automatically scheduled when certain threshold values are exceeded. A single regeneration tally results if 10 to 30 percent of the trees per acre or total cubic foot volume is removed. A tally sequence is scheduled when more than 30 percent of either trees per acre or cubic foot volume is removed. You can change these threshold values.

Site preparations for automatic tallies are predicted from default equations. These equations predict the percentages of plots in the stand receiving each of the three site preparations (none, mechanical, and burn). Important independent variables used to predict site preparations include residual overstory basal area, slope, aspect, habitat type, elevation, and topographic position.

Ingrowth

Ingrowth is the addition of new trees to the Prognosis Model tree list in the absence of disturbance in recent cycles. Ingrowth occurs every 20 years after the completion of a regeneration period if there are no regeneration activities scheduled for the next cycle. The objective is to account for regeneration that continues to become established in sparsely stocked stands or under the canopy of the overstory. Tree records that are created for ingrowth tallies can include trees up to 20 years old, so an assortment of tree sizes is added to the tree list when ingrowth is represented.

Data used to develop the regeneration model was not explicitly gathered to develop an ingrowth model. However, the data did contain many plots representing conditions where ingrowth occurs—fairly dense overstories within stands where no harvesting had been done. These undisturbed portions of selection/sanitation/salvage harvests were sampled because of the systematic arrangement of plots in the study.

To account for ingrowth, the regeneration model predicts trees that would occur on undisturbed plots. These trees survive and grow based on tree, site, and stand characteristics. Ingrowth is reported in an abbreviated summary table that simply lists trees per acre by species.

Stump Sprouts

Some variants of the Prognosis Model represent species that produce sprouts from stumps or roots of harvested trees. For these variants, version 2 of the Regeneration Establishment Model adds regeneration sprouts to the tree list following harvests.

The species that sprout will change with the variant of the Prognosis Model. The biology of sprouting species will need to be modeled and incorporated into each variant—the regeneration model provides only the framework for incorporation of predictive equations. A separate regeneration summary table lists sprouting trees per acre and average height by species.

Data Requirements and Inventory Considerations

The regeneration model is designed to utilize inventory data from a sample of 1/300-acre circular plots that are representative of the stand. Each plot is projected separately so that unique properties of the plot influence its predicted contribution to the stand. Stand inventory values are substituted for plots that have missing information.

The number of inventory plots to use as input to the model depends, in part, on microsite variation within the stand. A minimum of five plots is recommended. The regeneration model replicates the number of plots until 50 are available for projection. Plot replication means there will be within-stand variation in seedling density, species composition, and heights.

The use of plot sizes other than 1/300-acre is permissible if it can be assumed that site descriptions are applicable. This simply means that information recorded for a different plot size would apply to a 1/300-acre plot centered at the same location. However, the reported probability of stocking is for 1/300-acre plots.

The data for the model were collected on individual 1/300-acre plots. To fully utilize the model, you should:

- Inventory microsite attributes at each sample point—slope percent, aspect, site disturbance, habitat type, topographic position, and plot stockability (see appendix A).
- Set minimum height requirements for trees to be recorded as established. Regeneration is considered established if at least 0.5 foot tall for shade tolerant species and 1.0 foot tall for shade intolerant species (see table 1). Maximum size for all regeneration is 2.95 inches d.b.h.
- Record overstory basal area and species composition at each plot.

KEYWORDS

The regeneration model is controlled through the use of keywords. The first keyword in a regeneration model keyword file is always ESTAB and the last one is always END. The ESTAB keyword means that records to follow are for the regeneration model, and the END keyword signifies the end of regeneration keywords. Each keyword is left-justified in the first eight columns of the record. Starting in column 11, there are seven 10-column fields, called *parameter fields*, which are used to transmit numeric data. Numeric data in the parameter fields should be right-justified or should include a decimal point. Not all seven parameter fields are used on every keyword record.

Keywords fall into two general classes—those used to specify silvicultural prescriptions and those used to modify predictions. A brief definition of each keyword is given below and parameter fields are shown in table 4. Example keyword record files are shown in appendix B. Regeneration model keywords and their functions are explained fully in appendix C.

Table 4—Keywords and parameter fields for the Regeneration Establishment Model

Keyword	Parameter fields 1	2	3	4	5	6	7
ESTAB	Year of disturb.						
MECHPREP	Year of prep.	Percent					
BURNPREP	Year of prep.	Percent					
PLANT	Year to plant	Species code	Trees per acre	Percent survival	Tree age	Average height	Shade code
NATURAL	Year to input	Species code	Trees per acre	Percent survival	Tree age	Average height	Shade code
BUDWORM	Begin year	End year					
PLOTINFO	Dataset number						
RESETAGE	Year of change	New age					
HABGROUP							
OUTPUT	Output code	Dataset number					
TALLY	Year to begin	Year of disturb.					
TALLYONE	Year of tally 1	Year of disturb.					
TALLYTWO	Year of tally 2	Year of disturb.					
EZCRUISE							
STOCKADJ	Year to begin	Multi-plier					
HTADJ	Year to begin	Species code	Value (feet)				
SPECMULT	Year to begin	Species code	Multi-plier				
NOINGROW							
NOAUTALY							
THRSHOLD	Lower percent	Upper percent					
RANNSEED	New seed						
MINPLOTS	Number of plots						
END							

Keywords for Silvicultural Prescriptions

ESTAB Begin keywords for the Regeneration Establishment Model and enter the year of disturbance. A tally sequence starts at the year entered in field 1.

field 1: Year of the regeneration harvest.

MECHPREP
BURNPREP Set percentages of site preparations for plots in the stand. The MECHPREP keyword is for mechanical site preparation and BURNPREP is for burning.

field 1: Year of site preparation.

field 2: Percentage of plots to be treated.

PLANT
NATURAL Specify regeneration that is to be added to the stand. PLANT is for planting trees. NATURAL is for Prognosis Model variants that do not have equations predicting natural regeneration. It is permissible to use the PLANT and NATURAL keywords in the same projection.

The PLANT and NATURAL keywords are similar. The reason for using separate keywords is that different economic costs are associated with planting versus natural regeneration. These costs serve as input to an economic analysis program called CHEAPO (Horn and others 1986), that is part of the Prognosis Modeling system.

field 1: Year the activity is to be done.

field 2: Numeric species code, see table 1.

field 3: Trees per acre.

field 4: Percent survival at the end of the cycle. A blank field is interpreted as 100 percent survival.

field 5: Seedling age at planting time or average seedling age for natural regeneration; default is 2 years.

field 6: Optional field to assign heights to seedlings.

field 7: Shade code. Trees created through use of the PLANT or NATURAL keyword can be established uniformly among plots, in greater numbers on plots with more basal area, or in greater numbers on plots with less basal area.

BUDWORM The default condition for the regeneration model is no budworm defoliation. To simulate the effects of budworm defoliation on regeneration success, use this keyword to input defoliation histories for western spruce budworm. If budworm effects are represented by the Budworm Model (Crookston and others 1990), this keyword is not necessary. The two parameter fields define the beginning and ending years of an outbreak.

field 1: Year defoliation began.

field 2: The last year of defoliation. A zero or blank field is replaced with the value in field 1, resulting in 1 year of defoliation.

PLOTINFO Read plot values for slope, aspect, habitat type, topographic position, and site preparation from supplemental data records. See appendix A for coding supplemental data records.

field 1: Identify where the supplemental data records are found. A blank field means the supplemental data records follow the PLOTINFO keyword.

RESETAGE Set a new stand age. This keyword is also a Prognosis Model keyword.

field 1: Year that stand age is to be changed; default is 1.0.

field 2: New stand age; default is 0.0.

HABGROUP Print a table showing habitat types within the groups shown in the regeneration summary output table.

OUTPUT Specify printing of regeneration summary tables.

field 1: Code for printing summary tables.

field 2: A data set reference number for redirection of output from the regeneration model.

TALLY An optional way to schedule a tally sequence.

field 1: Year the tally sequence is to begin.

field 2: Optional field to supply the year of disturbance.

TALLYONE
TALLYTWO Schedule one or two tallies of regeneration at specific years. Use of either of these keywords takes precedence over the tally sequence scheduled by the ESTAB keyword or the TALLY keyword.

field 1: Year of the tally.

field 2: Optional field to supply the year of disturbance; default is the year on the ESTAB keyword record.

EZCRUISE A seldom-used keyword that applies to inventories where regeneration was not recorded. This keyword needs to be used only if (1) the inventory did not include regeneration less than 3 inches d.b.h. and (2) the regeneration model will be called within 20 years of the inventory year.

END End of keywords for the Regeneration Establishment Model. This keyword must be the last record in each set of regeneration model keywords.

Keywords for Modifying Predictions

The following keywords modify the behavior of the regeneration model. Applications might include simulation of forest pests, advances in regeneration technology, or new silvicultural treatments.

STOCKADJ Multiplier used to adjust the probability of stocking upward or downward.

field 1: Year the multiplier takes effect.

field 2: Multiplier; default is 1.0.

HTADJ Species-specific adjustment for tree heights.

field 1: Year adjustment value takes effect.

field 2: Numeric species code; default is all species. See table 1 for species codes.

field 3: A positive or negative value in feet.

SPECMULT Species-specific multiplier to expand or contract the probability of a species' occurrence.

field 1: Year multiplier takes effect.

field 2: Numeric species code; default is all species. See table 1 for species codes.

field 3: Multiplier.

NOINGROW Prevent simulation of ingrowth.

NOAUTALY Prevent automatic tallies following thinnings.

THRSHOLD Change threshold values that schedule automatic regeneration tallies following thinnings. Percentages refer to the removal of either trees per acre or total cubic foot volume.

field 1: New lower percent; default is 10 percent.

field 2: New upper percent; default is 30 percent.

RANNSEED Reseed the pseudorandom number generator used by the Regeneration Establishment Model.

field 1: New seed.

MINPLOTS The minimum number of plots to process. Plots are repeatedly doubled until the value in field 1 is reached.

field 1: Minimum number of plots to process.

Example 1: Simple Case

An example of using the regeneration model will be the same stand (S248112) used by Wykoff and others (1982). In their example, a shelterwood cutting of 35 trees per acre was simulated. Leave trees were primarily Douglas-fir and grand fir. Stand S248112 is on the St. Joe National Forest at an elevation of 3,400 feet, northwest aspect, 30 percent slope, and the habitat type is *Tsuga heterophylla/Clintonia uniflora*. The keyword record file needed to simulate this silvicultural prescription is shown in figure 3. The plot information coded on the first tree record of each plot will automatically be read when a positive number is coded in field 2 of the TREEDATA keyword record.

The regeneration model is invoked by two records in the keyword record file (fig. 3). The first keyword is ESTAB with the year of disturbance in field 1 and the second is END denoting the end of regeneration keywords. The regeneration model summary output table is shown in figure 4.

```
STDIDENT
S248112  SHELTERWOOD PRESCRIPTION FROM THE USER'S MANUAL
DESIGN                                                  11.0       1.0
STDINFO        118.0     570.0       57.0     315.0      30.0       34.0
INVYEAR       1977.0
NUMCYCLE        10.0
THINPRSC      1980.0     0.999
SPECPREF      2010.0       2.0      999.0
SPECPREF      2010.0       7.0     9999.0
THINBTA       2010.0     157.0
SPECPREF      2040.0       3.0     -999.0
SPECPREF      2040.0       4.0      -99.0
THINBTA       2040.0      35.0
ESTAB         2037.0
END
TREEDATA        15.0       1.0
 101001     11LP  115 10 73  0   04 0 0 0 0 0 0112032057031
 101002     31DF    1  0  2  0   06 0 0 0 0 0 022
 102003     11WH   65 23 30  0   08 0 0 0 0 0 0113031557031
 102004     11L    79  6 75  0   03 0 0 0 0 0 011
 102005     18L   346  0  0  0   0010 0 0 0 0 032
 103006     11L    80  7 63 56   0396 0 0 0 0 0225031757032
 103007     11GF   62 20 38  0   05 0 0 0 0 0 011
 103008     11L    84  0  5  0   04 0 0 0 0 0 011
 103009     11LP   95 11 60  0   03 0 0 0 0 0 011
 104010     11DF   40  0 20  0  503 0 0 0 0 0 0113032562041
 104011     11L    82 12 65  0   0550 0 0 0 0 011
 105012     11DF   12  0 11  0  426 0 0 0 0 0 0224031057051
 105013     11DF   19  0 13  0  475 0 0 0 0 0 022
 105014     18LP   72  0  0  0   0011 0 0 0 0 032
 105015     31GF    1  0  3  0   07 0 0 0 0 0 022
 105016     11GF   53  9 27  0   07 0 0 0 0 0 011
 106017     11DF  100 10 65  0   04 0 0 0 0 0 0113031652033
 106018     11GF   61 12 38  0   08 0 0 0 0 0 011
 106019     11DF  127 16 67  0   04 0 0 0 0 0 011
 107020     00      0  0  0  0   00 0 0 0 0 0 080 5 4526024
 108021     11LP   96  5 60  0   03 0 0 0 0 0 0221018026031
 108022     11DF  104  9 55 49   0597 0 0 0 0 022
 108023     11LP   85  0  0  0   03 0 0 0 0 0 011
 109024     11GF  109 10 65  0   07 0 0 0 0 0 0113031557031
 109025     11DF   94 18 60  0   04 0 0 0 0 0 011
 110026     11C    32  6 17  0  325 0 0 0 0 0 0222032053031
 110027     11C     1  0  2  0   07 0 0 0 0 0 022
 110028     11C    58 10 28  0   07 0 0 0 0 0 011
 110029     11C    50 10 25  0  373 0 0 0 0 0 011
 111030     11GF   66 14 30  0   07 0 0 0 0 0 0113031057032
-999
PROCESS
STOP
```

Figure 3—Keyword record file to project stand S248112. Note that plot information is printed in bold typeface on the first tree record for each plot. This plot information will be read when a positive number is recorded in field 2 of the TREEDATA keyword record. Appendix A explains coding plot information on tree inventory records.

```
--------------------------------------------------------------------------
                 REGENERATION ESTABLISHMENT MODEL VERSION 2.0
                 STAND ID: S248112      MANAGEMENT CODE: NONE
--------------------------------------------------------------------------

 SITE PREP SUMMARY                 PLOT HABITAT TYPE SUMMARY
 -----------------    ----------------------------------------------------
PREP:NONE MECH BURN   SERIES:<--- DF --> <--- GF -->  C WH <--- SAF & MH -->
YEAR:2037 2037 2037    GROUP: 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16
 PCT:  90   10    0   #PLOTS: 0  0  1  0  0  0  1  0  1  6  0  0  1  0  0  0

NOTE:  1 NON-STOCKABLE PLOTS EXCLUDED FROM THIS SUMMARY.

TALLY 1 AT 10 YEARS.  PROBABILITY OF STOCKING IS 0.7353 IN THE FALL OF 2046.

     SUMMARY OF ALL          SUMMARY OF BEST          TREES < 3.0 IN. DBH
     TREES REGENERATING      TREES REGENERATING       BEING PROJECTED BY
     DURING THIS TALLY.      DURING THIS TALLY.       THE PROGNOSIS MODEL
     ------------------      ------------------       ------------------
             TREES % OF      TREES % OF  AVERAGE      TREES % OF
     SPECIES /ACRE TOTAL     /ACRE TOTAL HEIGHT       /ACRE TOTAL SPECIES
     ------- ----- -----     ----- ----- -------      ----- ----- -------
        WP    108.    9.       46.    8.   5.1          93.    9.   WP
         L      0.    0.        0.    0.   0.0           0.    0.    L
        DF    153.   13.      122.   20.   6.7         154.   15.   DF
        GF    345.   30.      165.   27.   3.0         298.   29.   GF
        WH    411.   36.      159.   26.   4.8         333.   33.   WH
         C     62.    5.       40.    7.   3.9          62.    6.    C
        LP      6.    1.        6.    1.   5.2           6.    1.   LP
         S     26.    2.       26.    4.   4.6          26.    3.    S
        AF     35.    3.       35.    6.   5.0          35.    3.   AF
        PP      4.    0.        4.    1.   3.7           4.    0.   PP
        --      0.    0.        0.    0.   0.0           0.    0.   --
             -----           -----                    -----
             1151.            603.                    1011.

TALLY 2 AT 20 YEARS.  PROBABILITY OF STOCKING IS 0.8040 IN THE FALL OF 2056.

     SUMMARY OF ALL          SUMMARY OF BEST          TREES < 3.0 IN. DBH
     TREES REGENERATING      TREES REGENERATING       BEING PROJECTED BY
     DURING THIS TALLY.      DURING THIS TALLY.       THE PROGNOSIS MODEL
     ------------------      ------------------       ------------------
             TREES % OF      TREES % OF  AVERAGE      TREES % OF
     SPECIES /ACRE TOTAL     /ACRE TOTAL HEIGHT       /ACRE TOTAL SPECIES
     ------- ----- -----     ----- ----- -------      ----- ----- -------
        WP     51.   10.       11.    6.   4.1          83.    7.   WP
         L      0.    0.        0.    0.   0.0           0.    0.    L
        DF     65.   12.       33.   18.   3.9         183.   14.   DF
        GF    166.   31.       55.   30.   1.8         380.   30.   GF
        WH    172.   32.       50.   27.   2.1         425.   34.   WH
         C     33.    6.        9.    5.   2.0          93.    7.    C
        LP      4.    1.        4.    2.   3.3          10.    1.   LP
         S      8.    1.        8.    4.   1.5          34.    3.    S
        AF     28.    5.       11.    6.   1.6          54.    4.   AF
        PP      2.    0.        2.    1.   5.0           4.    0.   PP
        --      0.    0.        0.    0.   0.0           0.    0.   --
             -----           -----                    -----
              530.            183.                    1266.
```

Figure 4—Regeneration model summary output table for example 1.

At the time of tally 1 in the fall of 2046, there are 1,151 regeneration-size trees per acre, of which 603 per acre are identified as best trees. The probability of stocking is 0.7353 after 10 growing seasons. Figure 4 also shows all trees in the tree list less than 3.0 inches d.b.h. that are being projected by the Prognosis Model. These trees can be a mixture of regeneration from an inventory, natural regeneration predicted by the model, or planted trees. In this case, the trees are all natural regeneration because no tree records from the 1977 inventory would be less than 3.0 inches d.b.h. in 2046, and no trees were planted in this example. The difference between the 1,151 total trees per acre and the 1,011 trees being projected are trees that were not added to the tree list because, after best trees are chosen on each plot, only five additional trees of each species are passed to the Prognosis Model.

Tally 2 is summarized in the fall of 2056 at which time 530 more trees per acre become established, 183 per acre of these being best trees. The list of trees less than 3.0 inches d.b.h. now contains new trees from tally 2 plus trees still in the inventory from tally 1.

Model output displays several aspects of the regeneration process:

- The probability of stocking, a number between 0.0 and 1.0, indicating the proportion of plots that are stocked.
- The inventory of total trees per acre, listed by species.
- A summary table of the best trees from the current tally of regeneration.
- The regeneration-size trees currently being projected by the Prognosis Model.

Figure 5 shows the Prognosis Model summary statistics table for stand S248112. Regeneration resulting from the shelterwood cut appears in the stand in 2047 and 2057. Note that the removals in 1977 and 2007 resulted in automatic tally sequences. Regeneration from the automatic tallies appears in the stand in 1987, 1997, 2017, and 2027.

SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA)

		START OF SIMULATION PERIOD									REMOVALS				AFTER TREATMENT					GROWTH THIS PERIOD			
YEAR	AGE	NO OF TREES	BA	SDI	CCF	TOP HT	QMD	TOTAL CU FT	MERCH CU FT	MERCH BD FT	NO OF TREES	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA	SDI	CCF	TOP HT	RES QMD	PERIOD YEARS	ACCRE PER	MORT YEAR	MAI MERCH CU FT
1977	57	536	77	184	95	63	5.1	1531	1076	4329	296	287	250	999	64	135	80	64	7.0	10	81	12	18.9
1987	67	933	89	230	107	68	4.2	1936	1603	6532	0	0	0	0	89	230	107	68	4.2	10	109	9	27.7
1997	77	1269	121	312	141	77	4.2	2939	2659	11221	0	0	0	0	121	312	141	77	4.2	10	129	15	37.8
2007	87	846	150	344	168	80	5.7	4080	3759	16728	703	1045	887	3938	113	192	127	80	12.1	10	145	18	46.1
2017	97	1061	143	344	154	87	5.0	4303	4124	19824	0	0	0	0	143	344	154	87	5.0	10	165	17	54.2
2027	107	1232	173	415	183	94	5.1	5778	5563	28215	0	0	0	0	173	415	183	94	5.1	10	174	28	62.6
2037	117	782	199	424	204	101	6.8	7238	6997	36385	750	5804	5612	29106	38	59	34	75	14.8	10	31	11	69.5
2047	127	947	44	130	40	72	2.9	1634	1576	8467	0	0	0	0	44	130	40	72	2.9	10	59	1	65.6
2057	137	1247	66	191	67	85	3.1	2217	2045	10943	0	0	0	0	66	191	67	85	3.1	10	88	4	64.2
2067	147	980	101	256	108	93	4.3	3059	2576	13680	0	0	0	0	101	256	108	93	4.3	10	103	11	63.4
2077	157	919	137	324	147	98	5.2	3977	3296	16860	0	0	0	0	137	324	147	98	5.2	0	0	0	64.0

Figure 5—Prognosis Model summary statistics for example 1.

Example 2: Using the NATURAL Keyword

This section shows how natural regeneration can be specified for Prognosis Model variants that do not have equations predicting natural regeneration. Suppose experience in an area shows that 10 years after a regeneration harvest expected regeneration would be 250 Douglas-fir per acre averaging 5.5 feet tall, 75 lodgepole pine per acre averaging 8.0 feet tall, and 120 ponderosa pine per acre averaging 6.0 feet tall. The regeneration model can be instructed to create appropriate tree records with the regeneration keyword record file shown in figure 6.

The regeneration summary output table for this example is shown in figure 7. The 445 trees per acre are added in the fall of 2009 as specified on the NATURAL keywords. Predicted natural regeneration is excluded, so the probability of stocking is 0.0.

```
STDIDENT
EXAMPLE2    USING THE "NATURAL" KEYWORD
DESIGN                                          10.0      0.0
STDINFO         104.0     260.0       0.0     315.0      30.0      45.0
INVYEAR        2000.0
TIMEINT           1.0       5.0
TIMEINT           2.0       5.0
NUMCYCLE         10.0
NOTREES
ESTAB          2000.0
NATURAL        2009.0       3.0     250.0                           5.5
NATURAL        2009.0       7.0      75.0                           8.0
NATURAL        2009.0      10.0     120.0                           6.0
END
PROCESS
STOP
```

Figure 6—Keyword record file for example 2.

Ingrowth for Prognosis Model variants that do not have equations predicting natural regeneration can be simulated through use of the Event Monitor (Crookston 1990). If you would like to add 50 ponderosa pine and 20 Douglas-fir per acre at 20-year intervals in example 2, add the following Event Monitor keyword record file to the keywords shown in figure 6. This Event Monitor file will add the 70 trees per acre every 20 years after cycle 3. Cycle lengths are assumed to be 10 years. A MECHPREP or BURNPREP keyword record specifying 0.0 percent site preparation is needed to keep all plots untreated.

```
IF
(FRAC(CYCLE/2) EQ 0 AND CYCLE GT 3)
THEN
ESTAB
NATURAL         0.0       10.0      50.0
NATURAL         0.0        3.0      20.0
MECHPREP        0.0        0.0
TALLYONE        9.0
END
ENDIF
```

```
------------------------------------------------------------------------------
                REGENERATION ESTABLISHMENT MODEL VERSION 2.0
                STAND ID: EXAMPLE2     MANAGEMENT CODE: NONE
------------------------------------------------------------------------------

 SITE PREP SUMMARY                 PLOT HABITAT TYPE SUMMARY
 -----------------      ------------------------------------------------------
PREP:NONE MECH BURN     SERIES:<--- DF --> <--- GF -->  C WH <--- SAF & MH -->
YEAR:2000 2000 2000      GROUP: 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16
 PCT:  48   30   22     #PLOTS: 0  0 10  0  0  0  0  0  0  0  0  0  0  0  0  0

TALLY 1 AT  5 YEARS.  PROBABILITY OF STOCKING IS 0.0000 IN THE FALL OF 2004.

     SUMMARY OF ALL          SUMMARY OF BEST          TREES < 3.0 IN. DBH
     TREES REGENERATING      TREES REGENERATING       BEING PROJECTED BY
     DURING THIS TALLY.      DURING THIS TALLY.       THE PROGNOSIS MODEL
     -------------------     -------------------      -------------------
             TREES % OF      TREES % OF  AVERAGE      TREES % OF
     SPECIES /ACRE TOTAL     /ACRE TOTAL HEIGHT       /ACRE TOTAL SPECIES
     ------- ----- -----     ----- ----- -------      ----- ----- -------
        WP      0.    0.        0.    0.   0.0           0.    0.   WP
         L      0.    0.        0.    0.   0.0           0.    0.    L
        DF      0.    0.        0.    0.   0.0           0.    0.   DF
        GF      0.    0.        0.    0.   0.0           0.    0.   GF
        WH      0.    0.        0.    0.   0.0           0.    0.   WH
         C      0.    0.        0.    0.   0.0           0.    0.    C
        LP      0.    0.        0.    0.   0.0           0.    0.   LP
         S      0.    0.        0.    0.   0.0           0.    0.    S
        AF      0.    0.        0.    0.   0.0           0.    0.   AF
        PP      0.    0.        0.    0.   0.0           0.    0.   PP
        --      0.    0.        0.    0.   0.0           0.    0.   --
             -----           -----                    -----
                0.              0.                       0.


TALLY 2 AT 10 YEARS.  PROBABILITY OF STOCKING IS 0.0000 IN THE FALL OF 2009.

NOTE: REPORTED PROBABILITY OF STOCKING DOES NOT INCLUDE TREES FROM PLANT
      AND NATURAL KEYWORDS.  SPECIES=   DF  LP  PP

     SUMMARY OF ALL          SUMMARY OF BEST          TREES < 3.0 IN. DBH
     TREES REGENERATING      TREES REGENERATING       BEING PROJECTED BY
     DURING THIS TALLY.      DURING THIS TALLY.       THE PROGNOSIS MODEL
     -------------------     -------------------      -------------------
             TREES % OF      TREES % OF  AVERAGE      TREES % OF
     SPECIES /ACRE TOTAL     /ACRE TOTAL HEIGHT       /ACRE TOTAL SPECIES
     ------- ----- -----     ----- ----- -------      ----- ----- -------
        WP      0.    0.        0.    0.   0.0           0.    0.   WP
         L      0.    0.        0.    0.   0.0           0.    0.    L
        DF    250.   56.      250.   56.   5.5         250.   56.   DF
        GF      0.    0.        0.    0.   0.0           0.    0.   GF
        WH      0.    0.        0.    0.   0.0           0.    0.   WH
         C      0.    0.        0.    0.   0.0           0.    0.    C
        LP     75.   17.       75.   17.   8.0          75.   17.   LP
         S      0.    0.        0.    0.   0.0           0.    0.    S
        AF      0.    0.        0.    0.   0.0           0.    0.   AF
        PP    120.   27.      120.   27.   6.0         120.   27.   PP
        --      0.    0.        0.    0.   0.0           0.    0.   --
             -----           -----                    -----
              445.            445.                     445.
```

Figure 7—Regeneration model summary output table for example 2.

MODEL BEHAVIOR

Changes in Site Conditions

The regeneration model represents a wide range of site and stand conditions. In this section, we show that model predictions are sensitive to changes in habitat type and elevation. To illustrate model behavior, five habitat types were chosen along an environmental gradient from low elevation warm, dry conditions to high elevation cool, moist conditions. Appropriate elevations were assigned to habitat types as follows:

Habitat type	**Elevation**
	Feet
Pseudotsuga menziesii/Physocarpos malvaceus	3,000
Abies grandis/Clintonia uniflora	3,500
Tsuga heterophylla/Clintonia uniflora	4,000
Abies lasiocarpa/Clintonia uniflora	5,000
Abies lasiocarpa/Xerophyllum tenax	5,500

The projections simulate results after 10 years for clearcuts on the Clearwater National Forest, east aspect, 20 percent slope, and 40 percent mechanical scarification. Results are summarized in table 5 and figure 8.

Table 5—Predicted regeneration at 10 years for five clearcuts on the Clearwater National Forest, east aspect, 20 percent slope, and 40 percent mechanical scarification

	Habitat type[1] and elevation				
	PSME/PHMA (3,000 ft)	ABGR/CLUN (3,500 ft)	TSHE/CLUN (4,000 ft)	ABLA/CLUN (5,000 ft)	ABLA/XETE (5,500 ft)
Probability of stocking:	0.222	0.532	0.758	0.534	0.576
Trees per acre by species:					
WP	0	38	99	10	14
L	14	9	9	10	52
DF	128	132	205	61	128
GF	0	341	596	163	28
WH	0	0	319	0	0
C	0	0	95	0	0
LP	5	12	59	6	97
S	0	16	9	38	24
AF	0	0	82	199	162
PP	20	7	0	0	0
MH	0	0	0	0	0
Total	167	555	1,473	487	505

[1]Species codes for habitat type abbreviations are given in table 3.

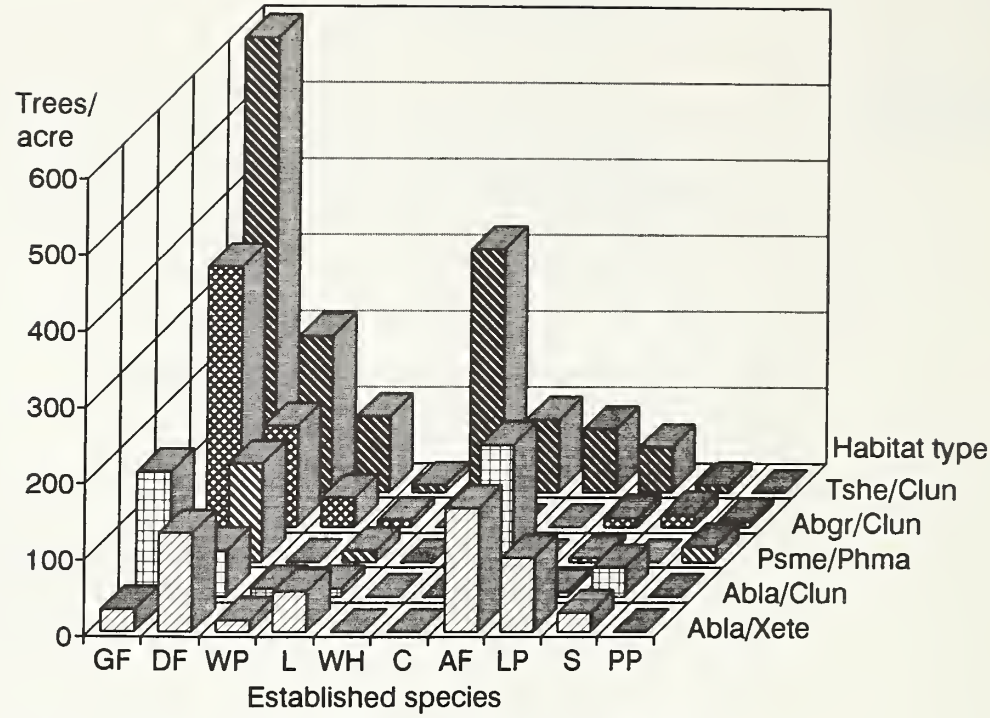

Figure 8—Trees per acre by species and habitat type at 10 years for five clearcuts on the Clearwater National Forest, east aspect, 20 percent slope, and 40 percent mechanical scarification.

The warm, dry *Pseudotsuga menziesii/Physocarpos malvaceus* habitat type has the lowest probability of stocking (0.222) and the fewest number of trees per acre (167). The best stocking occurs on the *Tsuga heterophylla/ Clintonia uniflora* habitat type where the probability of stocking is 0.758 and seedling density is 1,473 trees per acre. The other three habitat types have intermediate stocking probabilities and seedling densities.

Species composition is very much dependent on habitat type. Western hemlock and western redcedar occur only on the *Tsuga heterophylla/ Clintonia uniflora* habitat type in these examples. Subalpine fir does not occur on the warm, dry habitat types, and ponderosa pine does not occur on the cool, moist habitat types. The relationship of species occurrence by habitat types is taken from the publications of Pfister and others (1977), Steele and others (1981), and Cooper and others (1987).

Variation in Regeneration Estimates

The regeneration model produces plot-to-plot variation in the number of trees per plot, species composition, and initial tree heights. Stand statistics are the average of plot predictions, so a large number of plots reduces the random variation for the stand. Currently, plots are repeatedly doubled until at least 50 are available for projection. Even though plots are replicated,

some differences between runs can be expected when the calling sequence to the pseudorandom number generator is changed with the RANNSEED keyword.

This variation is illustrated by changing the pseudorandom number generator seed for example 1, but otherwise using the same keyword record file shown in figure 3. The pseudorandom number generator was reseeded in five additional runs using the RANNSEED keyword by choosing new six-digit seeds from a table of random numbers. Summaries of the best trees passed to the Prognosis Model are shown in table 6. Total numbers of best trees range from 603 to 682 trees per acre. Species composition of best trees varies slightly, but the overall pattern is fairly consistent.

The variation that results from changing the pseudorandom number generator seed mimics the variation found in nature. In an actual inventory of a regenerating stand, results would change if a different set of plots was chosen to represent the stand. This would happen if a different starting position was used to sample plots with a transect or sampling grid. Variation in actual inventories would also be expected if the harvesting was done at different years. Year-to-year fluctuations in weather, seed crops, animals, and so on would produce different results in the same stand if the stand was harvested one year as opposed to another.

Table 6—Projections of stand S248112 with the pseudorandom number generator reseeded. Results show the number of best trees predicted 10 years after the regeneration harvest in 2037. The default seed is 55329

	Pseudorandom number generator seed						
Species	Default	147565	493776	379183	861386	210988	Mean ±Std. Dev.
WP	46	52	41	25	32	46	40.3 ± 10.1
L	0	15	22	15	0	10	10.3 ± 8.9
DF	122	149	119	159	157	115	136.8 ± 20.3
GF	165	261	207	278	245	230	231.0 ± 40.6
WH	159	100	227	174	143	195	166.3 ± 43.7
C	40	42	41	21	16	31	31.8 ± 11.2
LP	6	5	8	0	1	3	3.8 ± 3.1
S	26	0	5	5	10	0	7.7 ± 9.7
AF	35	21	5	0	0	10	11.8 ± 13.8
PP	4	7	7	5	6	0	4.8 ± 2.6
MH	0	0	0	0	0	0	0.0
Total	603	652	682	682	610	640	644.8 ± 34.1

SUMMARY

Version 2 of the Regeneration Establishment Model is a part of version 6 of the Prognosis Model. This user's guide replaces the version 1 guide (Ferguson and Crookston 1984). Version 2 covers forests in western Montana, and central and northern Idaho. It includes the following climax habitat type series: Douglas-fir, grand fir, western redcedar, western hemlock, subalpine fir, and some of the mountain hemlock. The model can also represent the effects of western spruce budworm on regeneration success.

During field sampling, 12,128 1/300-acre plots were inventoried in 537 stands. The data represent common regeneration practices and site conditions in the Northern Rocky Mountains. A stratified random sample was used to choose conventionally harvested stands that were 2 to 20 years old. Use of conventionally harvested stands as study sites means that model predictions should reflect what can be expected from implementation of actual regeneration prescriptions.

Because the regeneration model is a part of the Prognosis Model, it is possible to predict stand development from one rotation to the next. Prediction of ingrowth into existing stands makes it possible to simulate uneven-age management and long-term succession.

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APPENDIX A: CODES AND INSTRUCTIONS FOR RECORDING PLOT VARIABLES

Plot data	Column(s) if PLOTINFO keyword record	Column(s) if tree inventory record	Comments and codes
Identification number	1-10	1-4	Assign the same numeric code as for tree records.
Slope	11-12	50-51	Code in percent.
Aspect	13-15	52-54	Code azimuth in degrees from north.
Habitat type	16-18	55-57	Use numeric codes provided by Pfister and others (1977), Steele and others(1981), or Cooper and others (1987).
Topographic position	19	58	1 = bottom 2 = lower 3 = mid-slope 4 = upper slope 5 = ridgetop
Site preparation	20	59	1 = none 2 = mechanical 3 = burn 4 = road cuts, road fills, and stockable road beds

APPENDIX B: EXAMPLE KEYWORD RECORD FILES FOR THE REGENERATION ESTABLISHMENT MODEL

The following is a keyword record file that contains the basic records necessary to make a complete Prognosis Model projection with a call to the regeneration model. Blank parameter fields will be assigned default values, so this keyword file should work for all variants.

```
STDIDENT
EXAMPLE      SIMULATE REGENERATION IN A CLEARCUT
DESIGN                                              10.0
STDINFO
INVYEAR        2000.0
NUMCYCLE         10.0
NOTREES
ESTAB          2000.0
PLANT          2001.0       1.0      300.0
END
PROCESS
STOP
```

Simple call to the Regeneration Model. A regeneration tally sequence will begin in 2000. This and the following examples show only the regeneration model keywords.

```
ESTAB          2000.0
END
```

Stand is disturbed in 2000, 40 percent of the plots will be scarified in 2001, and 20 percent of the plots will be burned in 2002. (The remaining 40 percent of the plots will remain untreated.)

```
ESTAB          2000.0
MECHPREP       2001.0      40.0
BURNPREP       2002.0      20.0
END
```

Stand is disturbed in 2000 with 40 percent of the plots scarified in 2001. Plant 300 western white pine per acre in 2002, 80 percent survival. Plant 200 western redcedar per acre in 2003, 60 percent survival.

```
ESTAB          2000.0
MECHPREP       2001.0      40.0
PLANT          2002.0       1.0      300.0       80.0
PLANT          2003.0       6.0      200.0       60.0
END
```

The inventory was taken in 1990 but trees less than 3 inches d.b.h. were not recorded. The harvest is to be simulated in 2000.

```
ESTAB          2000.0
EZCRUISE
END
```

(con.)

The impact of western spruce budworm on regeneration success is to be simulated. Harvest year will be 2000, so a defoliation history is needed for 5 years before the harvest through 20 years after the harvest. Budworm outbreak years will be 1995 through 1998, 2003 through 2008, and 2015 through 2020.

```
ESTAB          2000.0
BUDWORM        1995.0    1998.0
BUDWORM        2003.0    2008.0
BUDWORM        2015.0    2020.0
END
```

Plot information records are to be read as supplemental data records. Harvesting is to be done in 2000, so set a new stand age at that time.

```
ESTAB          2000.0
PLOTINFO
       1012032057031
       1023031557031
       1035031757032
       1043032562041
       1054031057051
       1063031652033
       107 5 4526024
       1081018026031
       1093031557031
       1102032053031
       1113031057032
      -999
RESETAGE       2000.0       0.0
END
```

The Prognosis Model is using 5-year cycle lengths (1990, 1995, 2000, 2005, 2010, 2015, . . .) and it is desired to report the regeneration only at 10 and 15 years after a harvest in 2000. Regeneration is added to the simulation just prior to the cycle boundary, so subtract 1 year from the desired tally year (for example: 2000 +10 -1 = 2009).

```
ESTAB          2000.0
TALLYONE       2009.0
TALLYTWO       2014.0
END
```

Several tally sequences are scheduled. Harvests are simulated in 2000, 2040, and 2080. Note that field 1 on the ESTAB keyword record is blank.

```
ESTAB
TALLY          2000.0    2000.0
TALLY          2040.0    2040.0
TALLY          2080.0    2080.0
END
```

(con.)

A stand is to be planted in 2001 following a harvest in 2000. Plant 600 white pine seedlings per acre, 100 percent survival. Natural regeneration is excluded from 2000 to 2030 to simulate a weeding.

```
ESTAB        2000.0
PLANT        2001.0      1.0       600.0
STOCKADJ     2000.0      0.0
STOCKADJ     2030.0      1.0
END
```

Control of competing vegetation results in increased seedling heights. Grand fir heights are 1.5 feet taller and Douglas-fir heights are 2.2 feet taller.

```
ESTAB        2000.0
HTADJ        2000.0      4.0         1.5
HTADJ        2000.0      3.0         2.2
END
```

The effect of defoliation by the Douglas-fir tussock moth is to be simulated. Suppose research shows that an infestation decreases the probability of Douglas-fir by 20 percent, grand fir by 50 percent, and subalpine fir by 25 percent. Therefore, the probability of Douglas-fir is 0.80 of its predicted value, grand fir is 0.50, and subalpine fir is 0.75.

```
ESTAB        2000.0
SPECMULT     2000.0      3.0        0.80
SPECMULT     2000.0      4.0        0.50
SPECMULT     2000.0      9.0        0.75
END
```

Ingrowth is to be excluded.

```
ESTAB        2000.0
NOINGROW
END
```

Automatic tallies are to be excluded.

```
ESTAB        2000.0
NOAUTALY
END
```

Both ingrowth and automatic tallies are to be excluded.

```
ESTAB        2000.0
NOINGROW
NOAUTALY
END
```

or

```
NOAUTOES
ESTAB        2000.0
END
```

(con.)

Threshold removal values that cause automatic calls to the regeneration model are to be changed to 20 and 45 percent. Removals in the range of 20 to 45 percent will result in one tally of regeneration. Removals of 45 percent or more will result in a regeneration tally sequence.

```
ESTAB          2000.0
THRSHOLD         20.0      45.0
END
```

The minimum number of plots to be processed is to be changed to 25.

```
ESTAB          2000.0
MINPLOTS         25.0
END
```

APPENDIX C: DETAILS FOR REGENERATION MODEL KEYWORDS

BUDWORM Input defoliation histories for western spruce budworm. Up to 20 BUDWORM keyword records can be present in a projection. The two parameter fields define the beginning and ending years, inclusive, of an outbreak. Data analysis showed that budworm defoliation history up to 5 years before the regeneration harvest affected regeneration following the harvest, so include budworm defoliation that occurs up to 5 years before a harvest and any time during a regeneration period. If budworm effects are represented by the Budworm Model (Crookston and others 1990), this keyword is not necessary.

field 1: Year defoliation began. A zero or blank results in an error message.

field 2: The last year of defoliation. A zero or blank is replaced with the value in field 1, resulting in 1 year of defoliation.

BURNPREP Set the percentage of plots that will receive burn site preparation. The sum of the mechanical and burn treatments should be less than, or equal to, 100 percent. When the sum of BURNPREP and MECHPREP is less than 100 percent, the remaining plots will be left untreated. If all plots are to be left untreated, specify either a MECHPREP or BURNPREP of 0.0 percent.

field 1: Year of burning.

field 2: Percentage of plots to be burned.

END End of keywords for the regeneration model. This keyword must be the last record in each set of regeneration model keywords.

ESTAB Begin keywords for the regeneration model and enter the year of disturbance. A tally sequence starts at the year entered in field 1. Prognosis Model removals are accomplished at the beginning of the cycle, so the year entered in field 1 should correspond with the beginning of a cycle. The only case in which the date entered in field 1 would not correspond to a cycle boundary is when an actual inventory was taken sometime during the regeneration period. In this case, enter the actual year of disturbance.

field 1: Year of the regeneration harvest.

EZCRUISE Use this keyword record if (1) the inventory did not include regeneration less than 3 inches d.b.h. and (2) the regeneration model will be called within 20 years of the inventory year. This keyword was designed for timber inventories where only overstory trees are recorded (therefore, it was an easy cruise because regeneration was not inventoried). The keyword is necessary because it is

not possible to tell from an inventory if regeneration was not being recorded or it was being recorded but none was found. When this keyword is used, the regeneration model will predict regeneration at the time of the inventory.

HABGROUP Print a table showing habitat types by habitat type group. The output is similar to table 3, but variants may have different groups. Habitat type groups for the regeneration model will usually differ from groups used in the Prognosis Model.

HTADJ Adjust regeneration tree heights before they are passed to the Prognosis Model. Heights after adjustment are bounded between the minimum establishment height listed in table 1 and the height of a tree 3 inches d.b.h.

field 1: Year adjustment value takes effect. Values remain in effect until replaced by another HTADJ value.

field 2: Numeric species code; default is all species.

field 3: Value in feet to be added to (positive value) or subtracted from (negative value) the assigned height.

MECHPREP Set the percentage of plots that will receive mechanical scarification. The sum of the mechanical and burn treatments should be less than, or equal to, 100 percent. If the sum of MECHPREP and BURNPREP is less than 100 percent, the remaining plots will be left untreated. If all plots are to be left untreated, specify either a MECHPREP or BURNPREP of 0.0 percent.

field 1: Year of scarification.

field 2: Percentage of plots to be scarified.

MINPLOTS Change the minimum number of plots to process. This keyword was designed to be used when computer space is limited.

field 1: Minimum number of plots; default is 50. Lowest value allowed is 20.

NATURAL Specify natural regeneration that will be added to the stand. Use a separate keyword record for each species. The NATURAL keyword is for use in variants that do not have equations predicting natural regeneration. Use of this keyword sets STOCKADJ to 0.0 and activates the NOINGROW and NOAUTALY keywords.

field 1: Year that trees per acre reaches the density coded in field 3. Default is 1.0.

field 2: Numeric species code, see table 1.

field 3: Trees per acre.

field 4: Percent survival at the end of the cycle. A blank field is interpreted as 100 percent survival.

field 5: Average seedling age in the year coded in field 1; default is 2 years.

field 6: Average seedling height. Heights are bounded between the minimum establishment height listed in table 1 and the height of a tree 3 inches d.b.h. Heights are assigned at the end of the cycle unless the cycle length is longer than 5 years. In this case, tree heights are assigned at 5 years, then a height increment is predicted for years 6 through the end of the cycle. See figure 6 for an example of assigning heights.

field 7: Shade code. Blank or 0 = default = seedlings occur uniformly on plots throughout the stand. 1 = seedlings occur more frequently on plots with more overstory basal area (in the shade). 2 = seedlings occur more frequently on plots with less overstory basal area (in the sun).

NOAUTALY Prevent automatic tallies following thinnings. The Prognosis Model keyword NOAUTOES invokes both the NOINGROW and NOAUTALY keywords.

NOINGROW Prevent simulation of ingrowth. The Prognosis Model keyword NOAUTOES invokes both the NOINGROW and NOAUTALY keywords.

OUTPUT Specify printing of regeneration summary tables.

field 1: Code for printing summary tables. 0 = suppress all output. 1 = default = print regeneration summary table (fig. 4).

field 2: Redirect output from the regeneration model to an external file. Place the data set reference number in this field.

PLANT Specify planted regeneration that will be added to the stand. Use a separate keyword record for each species.

field 1: Year of planting; default is 1.0.

field 2: Numeric species code, see table 1.

field 3: Trees per acre planted.

field 4: Percent survival at the end of the cycle. A blank field is interpreted at 100 percent survival.

field 5: Seedling age at time of planting; default is 2 years.

field 6: An optional field to assign heights to seedlings. Heights are bounded between the minimum establishment height listed in table 1 and the height of a tree 3 inches d.b.h. Heights are assigned at the end of the cycle unless the cycle length is longer than 5 years.

In this case, tree heights are assigned at 5 years, then a height increment is predicted for years 6 through the end of the cycle.

field 7: Shade code. Blank or 0 = default = plant seedlings uniformly on plots throughout the stand. 1 = plant more seedlings on plots with more overstory basal area (in the shade). 2 = plant more seedlings on plots with less overstory basal area (in the sun).

PLOTINFO An alternative way to input plot values for slope, aspect, habitat type, topographic position, and site preparation. This keyword is used when plot information is not contained on the tree data records. Stand values are assigned to missing or out-of-bounds plot values. See appendix A for coding instructions and appendix B for an example.

field 1: Identify the data set reference number for supplemental data records; by default, records follow the PLOTINFO keyword.

Supplemental Data Records:

Columns 1-10: Plot identification number coded the same as the variable ITRE in the Prognosis Model. Signify the end of supplemental data records with a negative number in columns 1-10.

Columns 11-12: Slope percent.

Columns 13-15: Aspect in degrees from true north.

Columns 16-18: Habitat type code.

Column 19: Topographic position code.

Column 20: Site preparation code.

RANNSEED Reseed the pseudorandom number generator used by the regeneration model.

field 1: New seed. If blank, the default seed is printed. If 0.0, a new seed is generated from the computer system clock—the result is printed in the Prognosis Model options selected table. Even-numbered seeds are incremented by 1 to make them an odd number.

RESETAGE Set a new stand age. This keyword is also a Prognosis Model keyword.

field 1: Year that stand age is to be changed (usually the year of disturbance); default is 1.0.

field 2: New stand age; default is 0.0.

SPECMULT Expand or contract the probability of a species' occurrence.

field 1: Year multiplier takes effect. The multiplier stays in effect until replaced by another SPECMULT multiplier.

field 2: Numeric species code; default is all species (but using the same multiplier for all species would not change the relative probabilities among the species). See table 1 for species codes.

field 3: Multiplier; default is 1.0.

STOCKADJ Adjust the predicted probability of stocking upward or downward. The probability of stocking will be multiplied by the value entered in field 2, but the product will be bounded within the interval [0,1]. The multiplier is calculated by dividing the desired probability of stocking by the predicted probability of stocking. As an example, suppose the regeneration model predicts the probability of stocking 10 years after a harvest is 0.40 and it is desired to raise this figure to 0.50 in a subsequent run. The value to enter in field 2 is

$$\frac{\text{desired probability of stocking}}{\text{predicted probability of stocking}} = \frac{0.50}{0.40} = 1.25$$

field 1: Year multiplier takes effect. The multiplier stays in effect until replaced by another STOCKADJ multiplier.

field 2: Multiplier; default is 1.0.

TALLY Schedule a tally sequence.

field 1: Year the tally sequence is to begin. Any time there is a Prognosis Model cycle boundary during the next 20 years, a tally of regeneration will be predicted. For example, four tallies would result if cycle lengths are 5 years.

field 2: Optional field to supply the year of disturbance. This value takes precedence over the value in field 1 of the ESTAB keyword record. If blank, the year of disturbance is determined from field 1 of the ESTAB keyword record.

TALLYONE Specify the year tally 1 is to be reported.

field 1: Year of tally 1. Regeneration is predicted at the end of the cycle, so subtract 1 year from the year of the desired cycle boundary. For example, if the Prognosis Model is using 5-year cycles, the regeneration harvest is simulated in 2000, and TALLYONE is desired at 10 years: field 1 of the TALLYONE keyword record should be coded 2009.0. Use of the TALLYONE keyword takes precedence over tally sequences scheduled by use of the

ESTAB or TALLY keyword, any ingrowth tallies, and any automatic tallies scheduled by thinnings.

field 2: Optional field to supply the year of disturbance. This value takes precedence over the value in field 1 of the ESTAB keyword record. If blank, the year of disturbance is determined from field 1 of the ESTAB keyword record.

TALLYTWO Specify the year tally 2 is to be reported.

field 1: Year of tally 2. If a TALLYTWO is scheduled without a TALLYONE being scheduled, the TALLYTWO is changed to a TALLYONE. Regeneration is predicted at the end of the cycle, so subtract 1 year from the year of the desired cycle boundary. For example, if the Prognosis Model is using 5-year cycles, the regeneration harvest is simulated in 2000, TALLYONE is desired at 10 years, and TALLYTWO is desired at 15 years: field 1 of the TALLYONE keyword record should be coded 2009.0 and field 1 of the TALLYTWO keyword record should be coded 2014.0.

field 2: Optional field to supply the year of disturbance. This value takes precedence over the value in field 1 of the ESTAB keyword record. If blank, the year of disturbance is determined from field 1 of the ESTAB keyword record.

THRSHOLD Change threshold values that schedule automatic regeneration tallies following thinnings. The value in field 1 must be lower than the value in field 2. Percentages refer to the removal of either trees per acre or total cubic foot volume.

field 1: New lower percentage. Values are bounded between 2.5 and 95.0 percent; default is 10 percent.

field 2: New upper percentage. Values are bounded between 5.0 and 97.5 percent; default is 30 percent.

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Ferguson, Dennis E.; Crookston, Nicholas L. 1991. User's guide to version 2 of the Regeneration Establishment Model: part of the Prognosis Model. Gen. Tech. Rep. INT-279. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 p.

This publication describes how to use version 2 of the Regeneration Establishment Model, a computer-based simulator that is part of the Prognosis Model for Stand Development. Conifer regeneration is predicted following harvest and site preparation for forests in western Montana, central Idaho, and northern Idaho. The influence of western spruce budworm (*Choristoneura occidentalis*) defoliation on regeneration success is also represented by the model. Model characteristics, prescription options, program control, and regeneration summaries are explained. Replaces General Technical Report INT-161 (Ferguson and Crookston 1984).

KEYWORDS: succession, stand simulation, Northern Rocky Mountains, forest planning, western spruce budworm, *Choristoneura occidentalis*

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